(12) UK Patent Application (19) GB (11) 2 144 711 A

(43) Application published 13 Mar 1985

(21) Application No 8418922

(22) Date of filing 25 Jul 1984

(30) Priority data

(31) 8312263 (32) 25 Jul 1983 (33) FR

(71) Applicant
Office National D'Etudes et de Recherches Aerospatiales, (France),
29 Avenue de la Division Leclerc, 92320
Chatillon-Sous-Bagneux, France

(72) Inventors
Alain Gaillet,
Claude Reboulet

(74) Agent and/or Address for Service
F. J. Cleveland & Company,
40-43 Chancery Lane, London WC2A 1JQ

(51) INT CL[4]
B25J 17/02

(52) Domestic classification
B8H 560 604 DV PD
U1S 1881 B8H

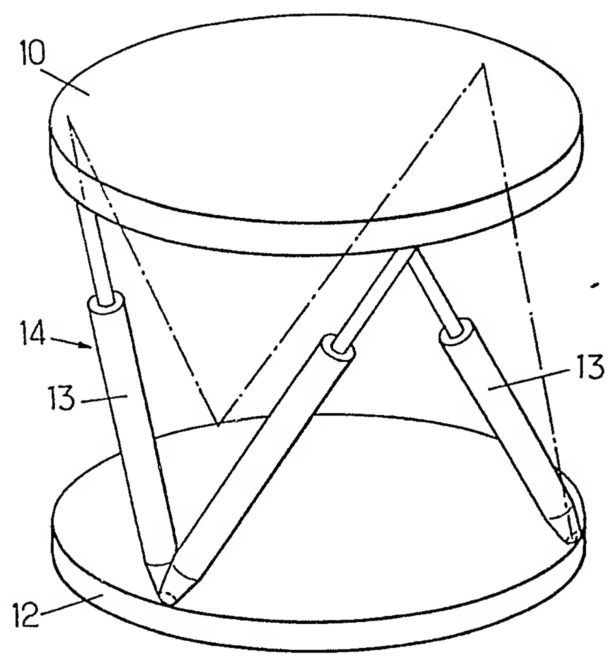
(56) Documents cited
None

(58) Field of search
B8H

(54) **Active compliant articulated device**

(57) A compliant active articulated device has two plates 10 and 12 connected by a cage like structure 14 comprising six oblique links. Each link is connected to the two plates at the end thereof by universal joints and each link includes an independently controlled double acting actuator 13 and a sensor connected to deliver a signal representative of the amount of extension of the actuator 13. The actuators 13 are identical and consist of gas pressure jacks. They are associated with a control system for controlling pneumatic pressures in two chambers of each actuator 13 for modifying the force exerted by, and length of, the actuator 13. Independent operation of the actuators 13 provides six degrees of freedom, (linear movements and rotations). The device is suitable for use in robot manipulators.

FIG.1.



GB 2 144 711 A

2144711

FIG. 4.

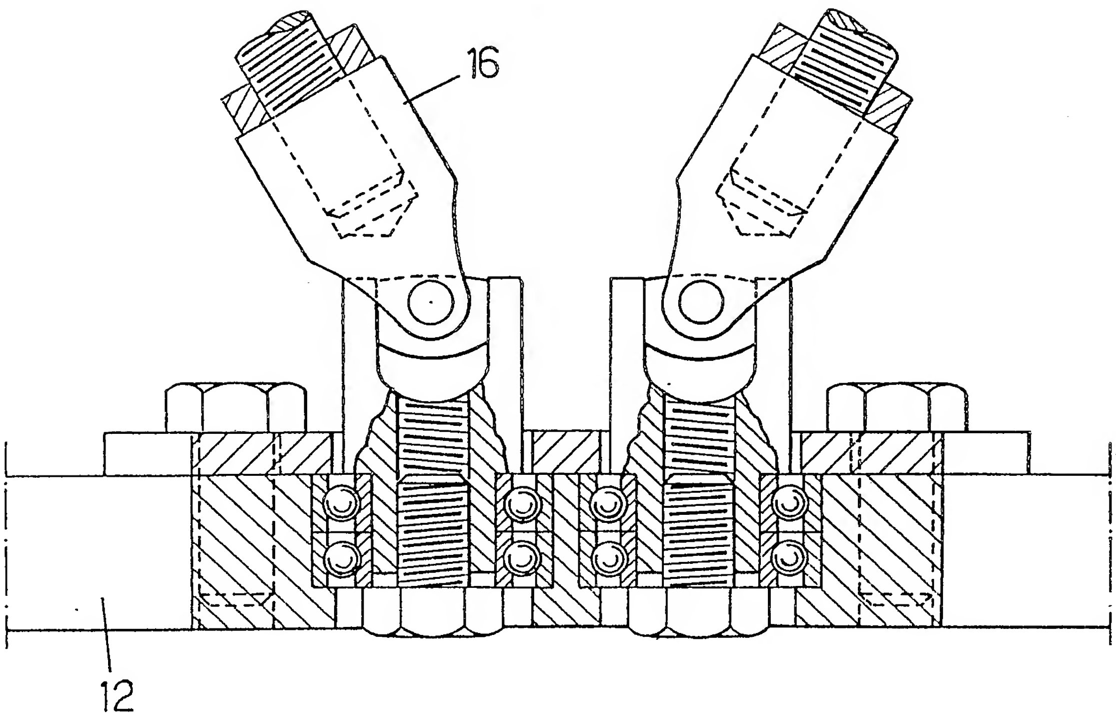
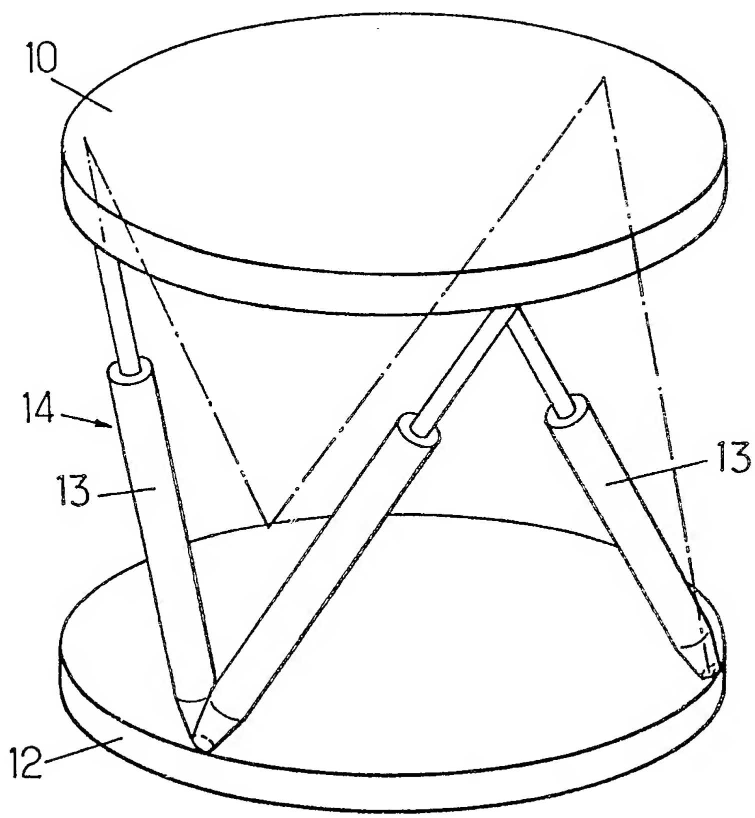


FIG. 1.



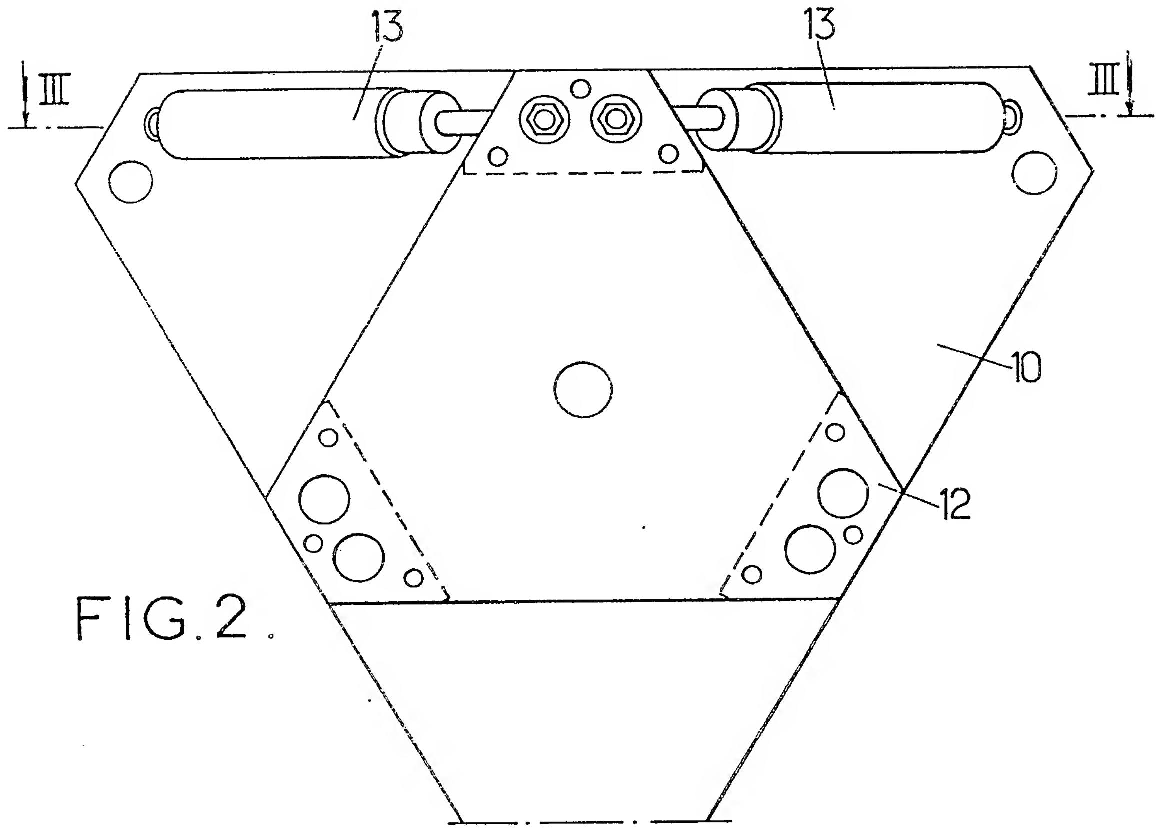


FIG. 2.

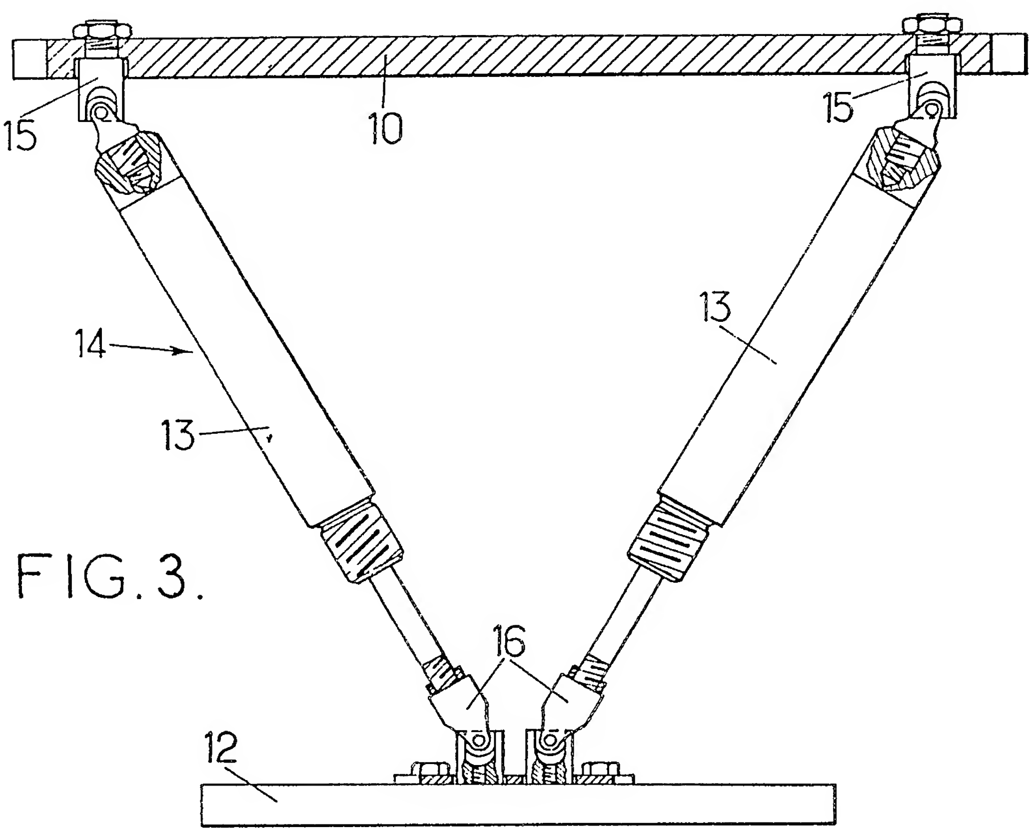


FIG. 3.

2144711

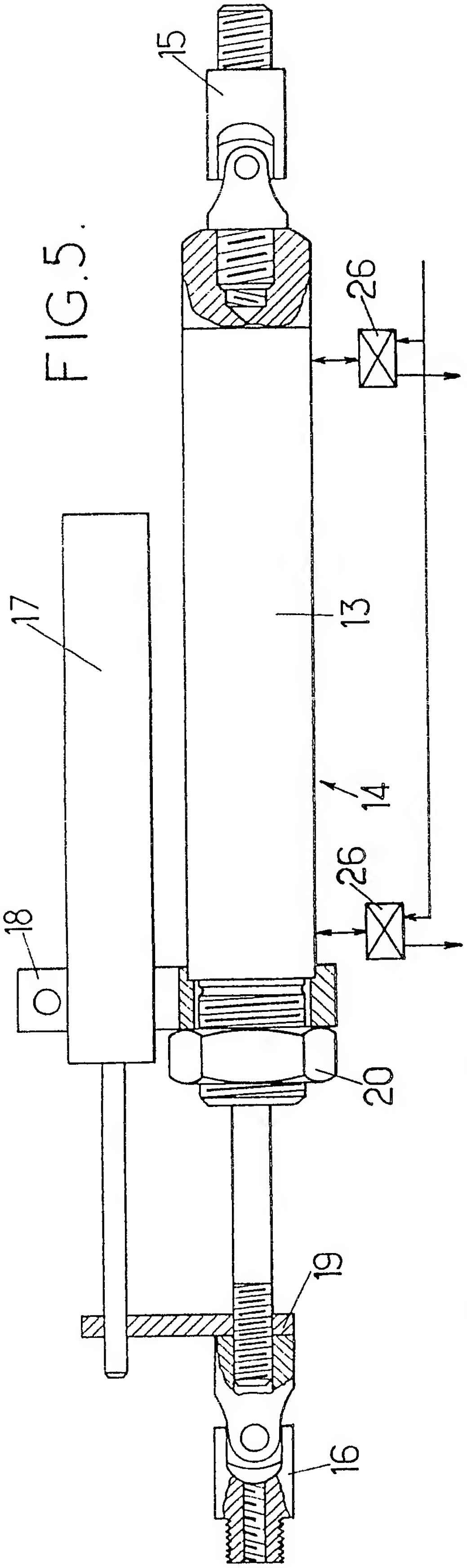


FIG.5.

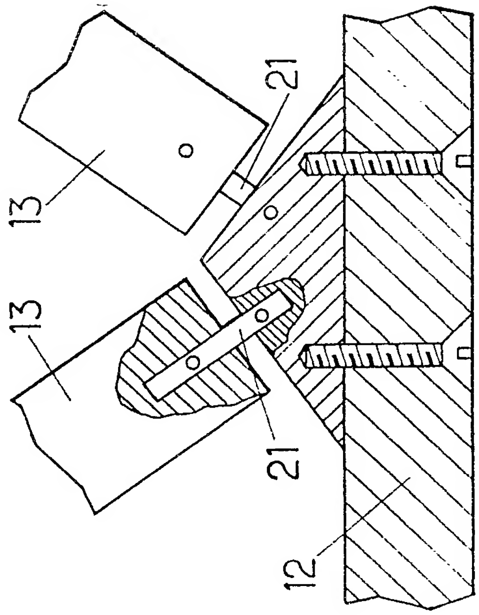


FIG.7.

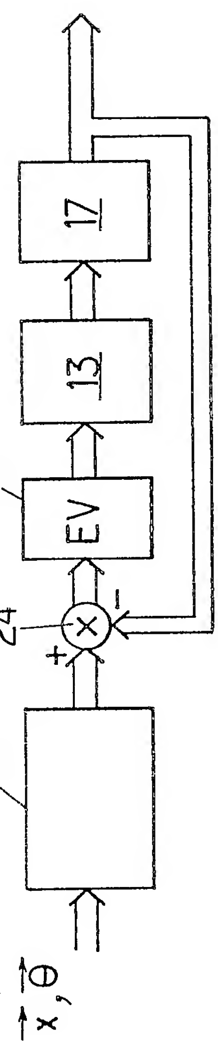


FIG.6.

SPECIFICATION

Active compliant articulated device

Background and summary of the invention

The invention relates to active compliant articulated devices having two plates mechanically connected by a cage-like structure having six links each of which is connected to the plates at the end thereof by U-joints. The invention is suitable for use in arms of robots which are movable with five or six degrees of freedom and then provide a wrist section for fine adjustment. It is however also suitable for use in platforms which can be moved linearly and angularly to bring them in a predetermined position for assistance in assembling processes which do not require a full robot.

With the advent of automatic manufacturing, complex tasks are to be fulfilled by robots, particularly insertion and assembling which require that the articulated device which is located between an end element (typically grippers) and the base of the manipulator, has an aptitude to resilient deformations such that a slight positioning error does not result into stresses of such a level that the system may be damaged. It is additionally necessary that the final positioning of the end element by achieved with a high degree of precision and that the magnitude of the efforts be monitored.

Compliant devices as described above are known in the art. Examples of such devices are described for instance in "A compliant device for inserting a peg in a hole", H. McCallion et al, The Industrial Robot, June 1979, and U.S. Patent No. 4, 283,153 to Brendamour. The device described by McCallion is a passive compliant device, in which each link consists of two parts connected by a resilient coupler and is connected to the plates by ball and socket joints. The resiliency of such a system is sufficient for accommodating alignment errors. On the other hand, since the structure is passive, it fails to provide the positioning precision which is required for a number of uses and does not provide monitoring and control of the efforts.

A number of active articulated devices for use as robot wrists are also known in the art. None of such devices fulfils the requirements as given above to a sufficient degree.

As a rule, a high degree of accuracy has generally been attained only at the cost of severe limitations as regards the load which may be carried. Such a high degree of accuracy further requires sophisticated actuators and detectors. The cost of the manipulator is consequently very high. However, the high degree of accuracy which is achieved by such a complex construction is not required, except during the final phase of work.

In addition, most of the articulated devices which have been designed in the past have not a sufficient number of degrees of freedom (French 2,462,607 for instance). Such device cannot be used on a robot, except if the arm of the robot already has a plurality of degrees of freedom which make it possible to position the end grippers. Then, the compliant device may be designed for having only those degrees of freedom which are required for positioning the grippers angularly.

Hydraulic or electric linear actuators have generally been used in the prior art active devices. Force monitoring and control with such actuators are rather difficult. One of the reasons is that speed rather than position is generally controlled on a hydraulic actuator, the rate of flow passing into or out of the actuator being controlled by a servo-valve. Electric actuators generally use a transmission including an endless screw. Such a transmission is not reversible and does not authorize force monitoring (Assembly Automation, February 1983, page 21). Hydraulic actuators have also been used for adjusting the position of the motion platform of a six degree of freedom simulator (U.S. No. 3,577,659 to Kail). Again such a system does not provide compliance and force control and it may be noted that compliance would be a deficiency rather than an advantage in such a system.

Last, force moninoting is quite tricky to obtain when the device does not exhibit all degrees of freedom which are required for insertion and assembly. For instance, force monitoring would be very difficult to achieve when the linear movements are transmitted through a robot arm, particularly due to the inertia of the parts and the reduction ratios which should be included in the linkage.

It is an object of the invention to provide an improved compliant articulated device which is active. It is a more particular object of the invention to provide such a device which is capable of displacing a load with six degrees of freedom without any transmission of movement from outside elements, whereby the inertia of the moving parts is reduced and detection is rendered easier. It is an other object of the invention to provide an active device in which the forces may be sensed and then controlled by processing signals received from displacement sensors.

According to the invention, there is provided a device having a independent linear actuator on each link, with a sensor for detecting the linear movement of the actuator located in parallel therewith. The actuators are pneumatically actuated (thereby achieving compliance), double acting and associated with a control system for adjusting the gas pressures in both chambers of the actuator. Such actuators are reversible, have an inherent flexibility due to compressibility of the gas, and make it possible to control the applied force. That result may be obtained by controlling flows into and out of the chambers of the actuator by an on-off valve controlled by current pulses having a variable duty cycle. The inherent flexibility of pneumatic actuators provides passive compliance in case of accidental contact. That compliance may be adjusted by modifying the stiffness of the servo-loops.

The links are preferably arranged for constituting three equilateral triangles which are evenly distributed about an axis of the device. Such a construction simplifies the mathematical matrix, which defines the correspondence between the forces applied by the actuators and the linear movements and rotations of low amplitude in a referenced triad. The

sensors associated with each actuator will typically consist of potentiometers or encoders delivering an electrical signal which may be processed directly by the control computer which is frequently associated with the robot.

The invention will be better understood from the following description of a particular embodiment of the invention, given by way of example.

Short description of the drawings

Figure 1 is a schematic isometric view showing the plates of the device according to the invention and the relative arrangement of three among the six actuators of the device;

Figure 2 is a bottom view of the device, two actuators only being shown;

Figure 3 is a cross-section along line III-III of Figure 2;

Figure 4 is a detailed view on an enlarged scale illustrating the connection between a couple of actuators and one of the plates of the device.

Figure 5 is a detailed view illustrating the connection between a detector and one of the actuators;

Figure 6 is a schematic view indicating how the control system and the servo-loop of the device may be arranged.

Figure 7 illustrates a modified arrangement for connecting the actuators to the end plates.

Detailed description of a particular embodiment

The articulated device which will now be described is suitable for rendering a manipulator able to carry out assembling. It may be located between the arm of a manipulator and an end tool, such as grippers. That device and the associated manipulator elements fulfil different functions. The device achieves positioning with a high accuracy and control of the forces exerted through the tool while the manipulator achieves coarse positioning during approach. The assembling operation may consequently be carried out in two steps. First, there occurs a coarse relative positioning of the two parts to be assembled. Then, the active articulated device achieves a low amplitude movement for accurate positioning.

Referring to Figures 1-3, there is shown a device which has two plates 10 and 12. For convenience, they will be designated as the upper plate and the lower plate. For simplicity, it will be assumed that the upper plate is for connection to the arm of a manipulator and the lower plate is for receiving the tool. The plates are connected by a cage-like structure 14. For achieving the six degrees of freedom which are necessary for assembling, the cage has six links each of adjustable length. The cage has a rotational symmetry of order 3 about the axis of the device. The links may be designed so that they define three adjacent equilateral triangles when they have their set or medium length. Then the matrix which provides correspondence between the lengths of the links and the linear and rotational movements is simplified.

For making it possible to vary the length of the links, each link consists of an actuator 13 connected to the upper plate 10 and to the lower plate 12. The actuators may be air jacks having a body or cylinder in which a piston connected to a rod reciprocates. The body of each actuator is connected to plate 12 by a U joint, consisting of a gimbal joint 15. The rod of the actuator is connected to the lower plate by a series arrangement of a second gimbal joint 16 and a ball bearing (Figure 4). Connection with the plates is by any conventional means, for instance screws and nuts.

Each actuator 13 is provided with a displacement sensor 17 comprising a linear potentiometer. The housing of the potentiometer may be connected to the body of the actuator 13 by a sleeve 18 and a nut 20, as shown in Figure 5. The slider of the potentiometer is carried by the rod of actuator 13. Connection may be through a plate 19 having a threaded connection with the end portion of the rod.

Independent operation of the six actuators 13 provides six degrees of freedom (linear movements and rotations). The amplitude of movement is limited by the range of action of the actuators only. Since the actuators are quite close to the tool, the inertia of the elements which move for fine adjustment is reduced to a minimum. Since pneumatic actuators are used, a tool may be controlled either for adjusting its amount of displacement, or for adjusting the force and torque exerted by the tool. The force applied by each actuator rod may be controlled by chopping energizing currents delivered to solenoid valves 26 connected via airlines to the chambers of each actuator. Experience has shown that, at least when the system is close to equilibrium, the pressure variation in a chamber of the actuator is substantially proportional to the duration of an electric pulse delivered to the corresponding solenoid valve for opening it. The amount of compliance may be adjusted by changing the "stiffness" of the response of a servo-loop which will be described later.

A force sensor may be located between each cardan joint or gimbal 16 and the associated plate 19. The output signal of that sensor may be applied to a servo-loop for regulating the force exerted by the actuator and maintaining that force at a predetermined value. Then the loop controls the solenoid valves 26. The amount of compliance may be modified by simultaneously increasing or decreasing the pressure in both chambers of the actuator.

The device as described above is associated with a source of gas under a pressure which is maintained at a constant value by a control system which may include a digital computer (not shown). The flowsheet of the system may be as shown in Figure 6. In Figure 6, the input signals $\vec{x}$ and $\vec{\theta}$ represent the linear and angular positions to be achieved in a reference triad fixed with respect to the manipulator arm. The input signals are applied to a computer 23 which is programmed to simulate the reverse of the geometric model of the device. The output signals of 23, which represent the lengths to be given to the actuators 13, are applied to a set of subtracting circuits 24 which also receive the counterfeedback signals from detectors 17. The output signals of the subtractor circuits are applied to the solenoid valves 25. If the sensors associated with the actuators for

providing a signal representative of the amount of extension are analog, A/D converters (not shown) should be provided.

As shown in Figure 7, the body and the rod of each actuator may be connected to plates 10 and 12 by needles or small diameter rods, which provide a sufficient stiffness in compression while being easily bent. Such a construction is particularly suitable for use in the micro-mechanical field. As compared with gimbal joints and ball bearings, needles have a lower range of relative movement. This is however not of trouble when the necessary movements have a low amplitude. On the other hand, such a connection has no lost motion.

The device according to the invention may as well be used as a wrist for grippers located at a stationary position for receiving a part into which movable grippers carried by a robot insert an other part. The compliance is provided by the support of the stationary part rather than by the grippers of the manipulator.

The abbreviation "U-Joint" has been used throughout this specification for the term "Universal Joint".

CLAIMS

1. A compliant active articulated device having two plates connected by a cage like structure comprising six links, each of which is connected to said two plates by U-joints, each said link including an independently controlled double acting actuator and a sensor connected to deliver a signal representative of the amount of extension of the actuator, said actuators being controlled by gas pressure and associated with a control system for controlling pneumatic pressures in two chambers of each actuator for modifying the force exerted by and length of the actuator.

2. Device according to claim 1, wherein said control system comprises a set of two solenoid valves each associated with one of said chambers of said actuator, and means for controlling said solenoid valves for adjusting the pressure independently in both chambers of said actuator.

3. Device according to claim 2, wherein said means for controlling the solenoid valves are adapted to deliver electric pulses having an adjustable duty cycle.

4. Device according to claim 1, wherein said links are arranged for defining equilateral triangles when they have a set length.

5. Device according to claim 1, wherein said sensors are potentiometers.

6. Device according to claim 1, wherein each said actuator has two parts, one of which is a body and the other of which is a rod, and wherein one of said parts is connected to one of said plates through a gimbal joint and the other is connected to the other plate through a gimbal joint and a bearing.

7. Device according to claim 1, wherein each said actuator has two parts, one of which is a body and the other of which is a rod, and wherein said rod and body are connected to respective ones of said plates by flexible rods adapted to bend upon application of flexure forces while resisting axial forces.

8. A compliant active articulated device having six degrees of freedom and including:

an upper plate,

a lower plate substantially aligned with said upper plate along an axis,

a cage-like structure having a rotational symmetry around said axis and mechanically connecting said upper plate and said lower plate, said structure comprising six links each obliquely extending between said upper plate and said lower plate and each link having:

a double action actuator having two relatively movable parts each connected to a respective one of said upper and lower plates by a U-joint, said actuator having two chambers so arranged that a gas pressure increase in one of said chambers causes extension of said actuator and pressure increase in the other of said chambers causes retraction of said actuator, and conversely,

a control system for independently controlling the gas pressures in the two chambers of each actuator for modifying the force exerted by and the length of the actuator while providing compliance,

and a sensor for delivering a signal representative of the extension of said actuator to said system.

9. A compliant active articulated device substantially as herein described with reference to and as shown in the accompanying drawings.

Printed in the UK for HMSO, D8818935, 1/85, 7102.
Published by The Patent Office, 25 Southampton Buildings, London, WC2A 1AY, from which copies may be obtained.